US011239718B2

(12) United States Patent
Patel et al.

(10) Patent No.: US 11,239,718 B2
(45) Date of Patent: *Feb. 1, 2022

(54) **WEDGES WITH Q-AXIS DAMPER CIRCUITS**

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(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 53 days.

This patent is subject to a terminal disclaimer.

(21) Appl. No.: **16/505,215**

(22) Filed: **Jul. 8, 2019**

(65) **Prior Publication Data**

US 2019/0334398 A1 Oct. 31, 2019

Related U.S. Application Data

(63) Continuation-in-part of application No. 15/470,525, filed on Mar. 27, 2017, now Pat. No. 10,541,580.

(51) **Int. Cl.**

H02K 3/48	(2006.01)
H02K 3/20	(2006.01)
H02K 3/52	(2006.01)
H02K 1/28	(2006.01)
H02K 3/12	(2006.01)
H02K 1/16	(2006.01)

(Continued)

(52) **U.S. Cl.**

CPC ***H02K 3/20*** (2013.01); ***H02K 1/14*** (2013.01); ***H02K 1/16*** (2013.01); ***H02K 1/24*** (2013.01); ***H02K 1/28*** (2013.01); ***H02K 3/12*** (2013.01); ***H02K 3/527*** (2013.01)

(58) **Field of Classification Search**

CPC .. H02K 3/00; H02K 3/12; H02K 3/18; H02K 3/46; H02K 3/48; H02K 3/52; H02K 3/527; H02K 15/00; H02K 15/12

See application file for complete search history.

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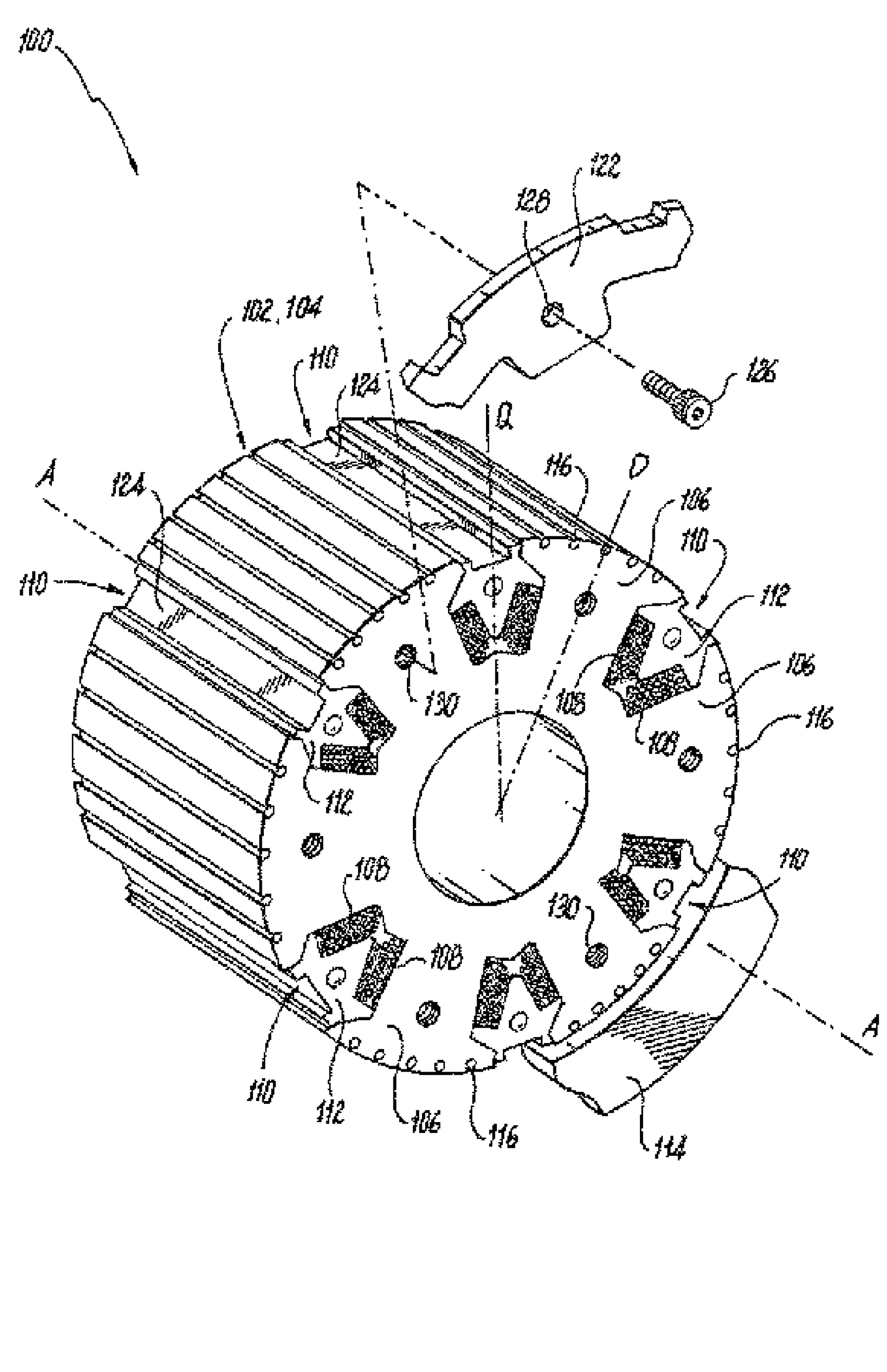
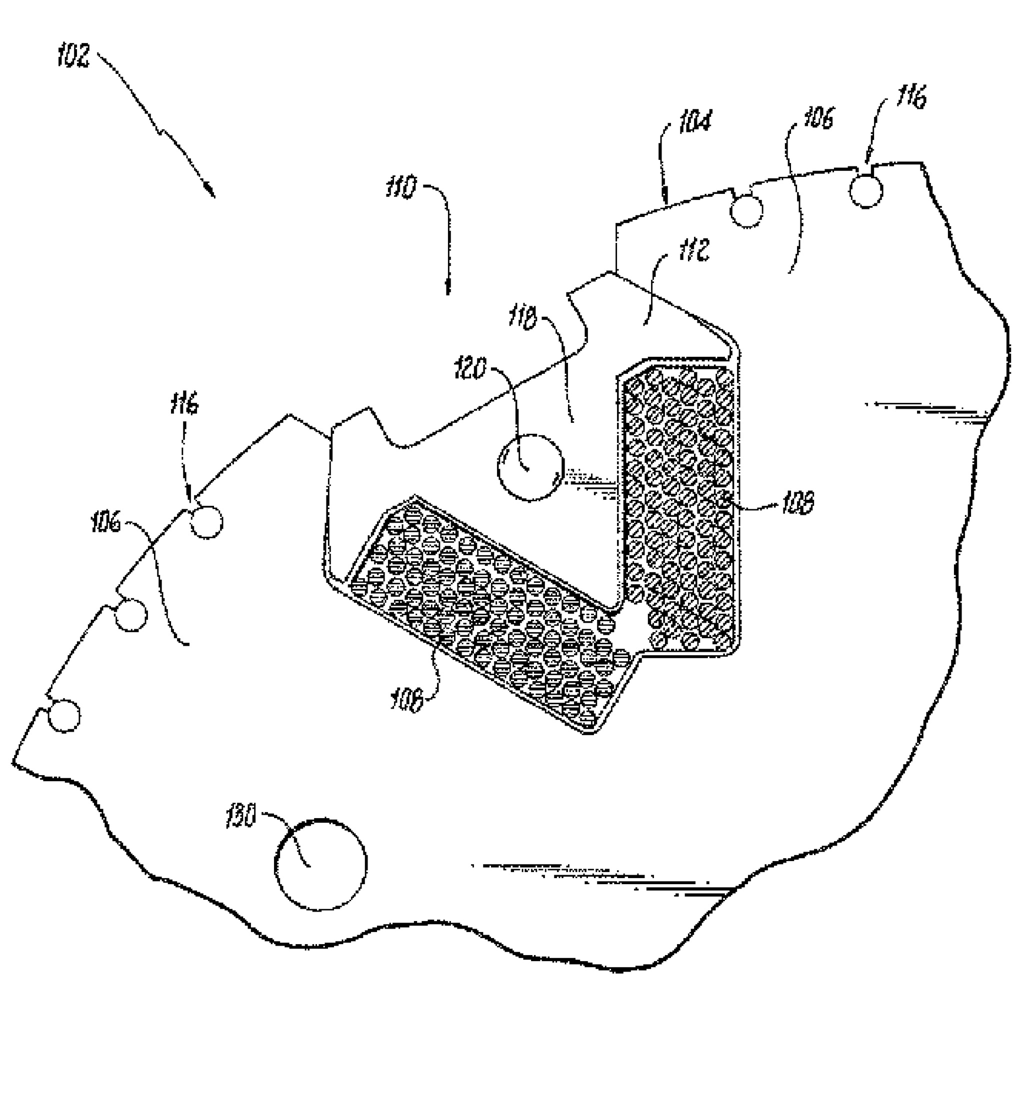
(57) **ABSTRACT**

A rotor for an electrical machine includes a rotor core having a plurality of circumferentially spaced apart rotor poles. A plurality of windings are seated in gaps between circumferentially adjacent pairs of the rotor poles. A respective wedge secures the windings in each gap configured to supply Q-axis damping. A pair of end plates are connected electrically to the wedges at opposing longitudinal ends thereof thereby completing a Q-axis winding circuit for each wedge.

10 Claims, 7 Drawing Sheets





(51) **Int. Cl.**
H02K 1/24 (2006.01)
H02K 1/14 (2006.01)

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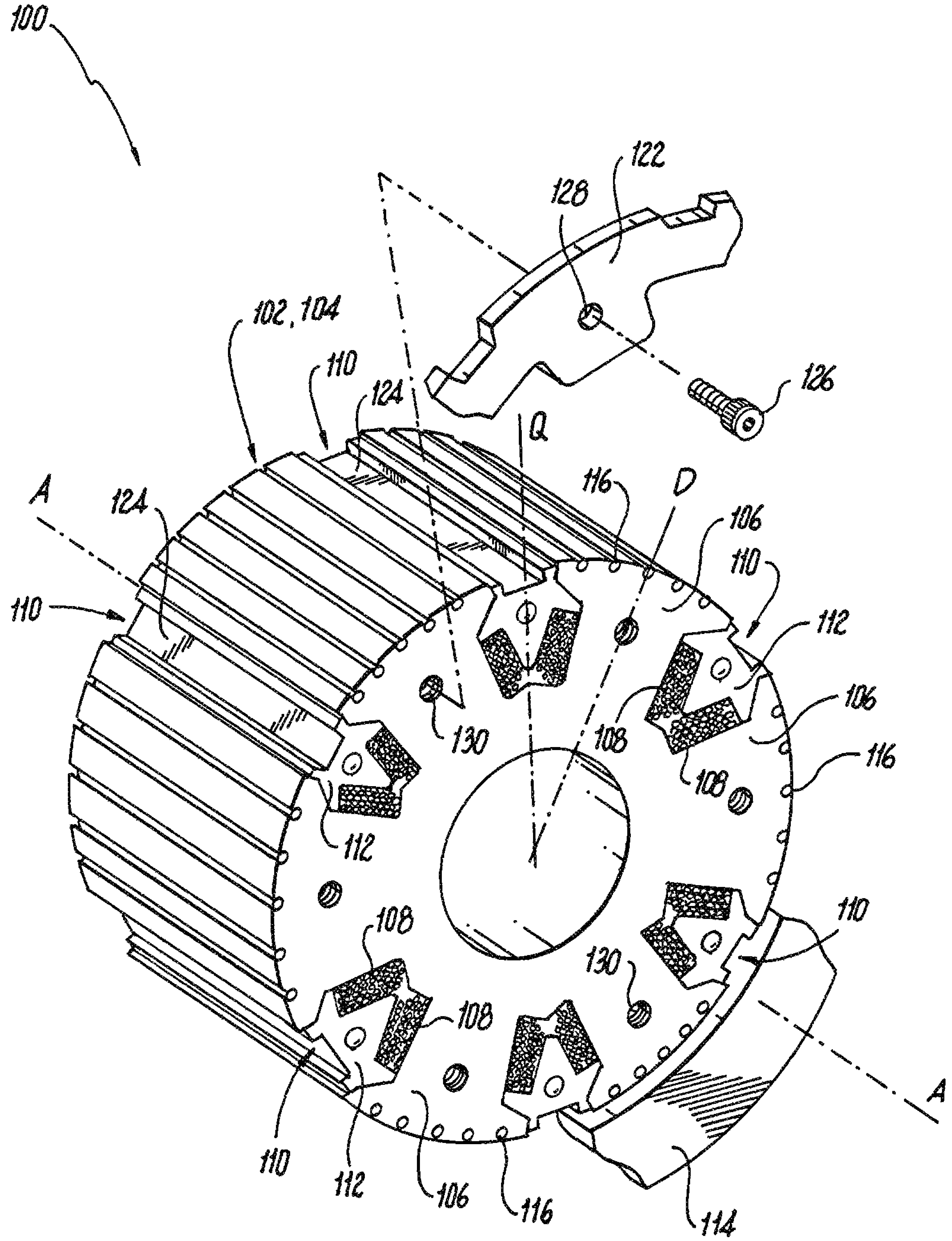
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Fig. 1

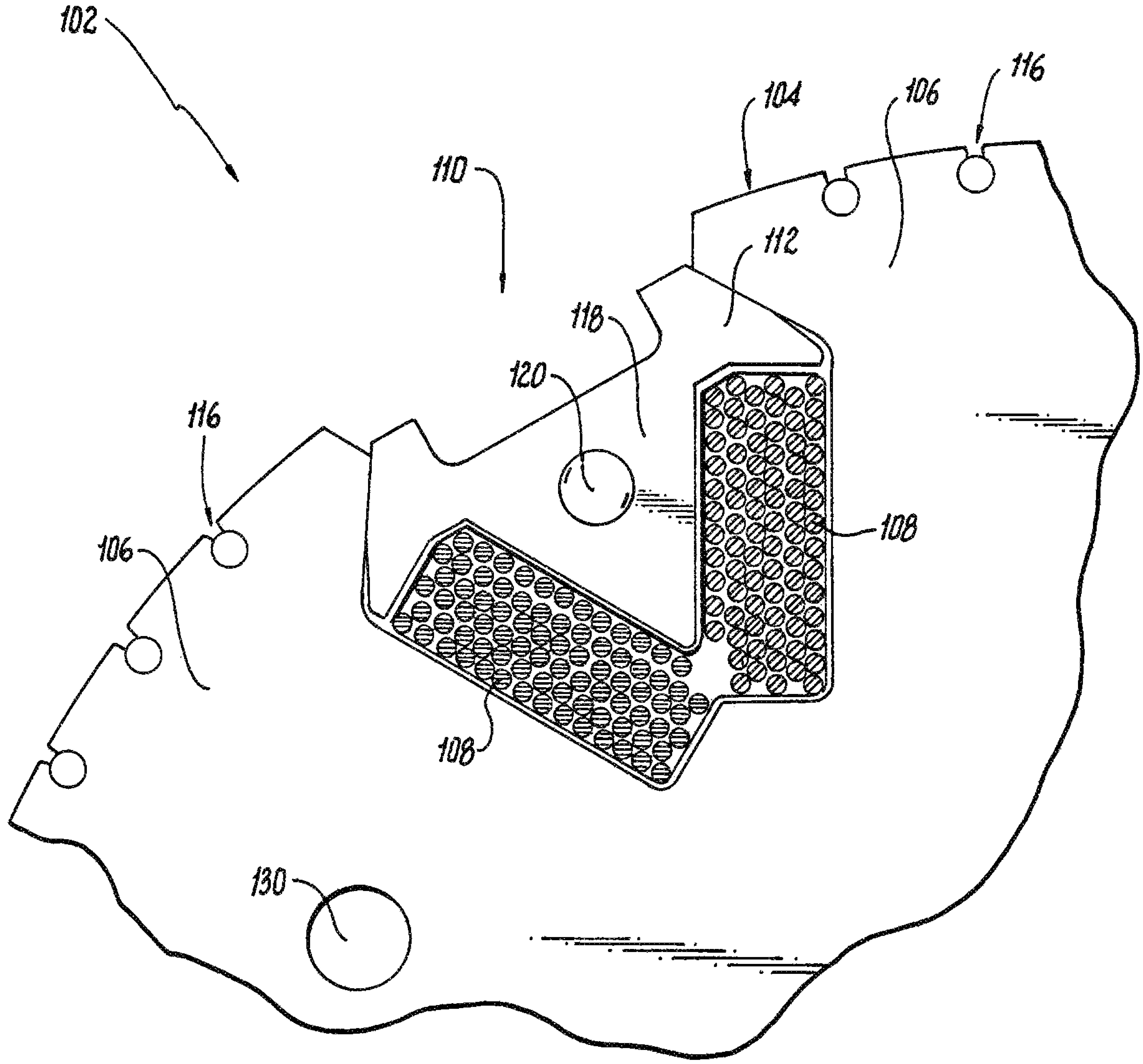


Fig. 2

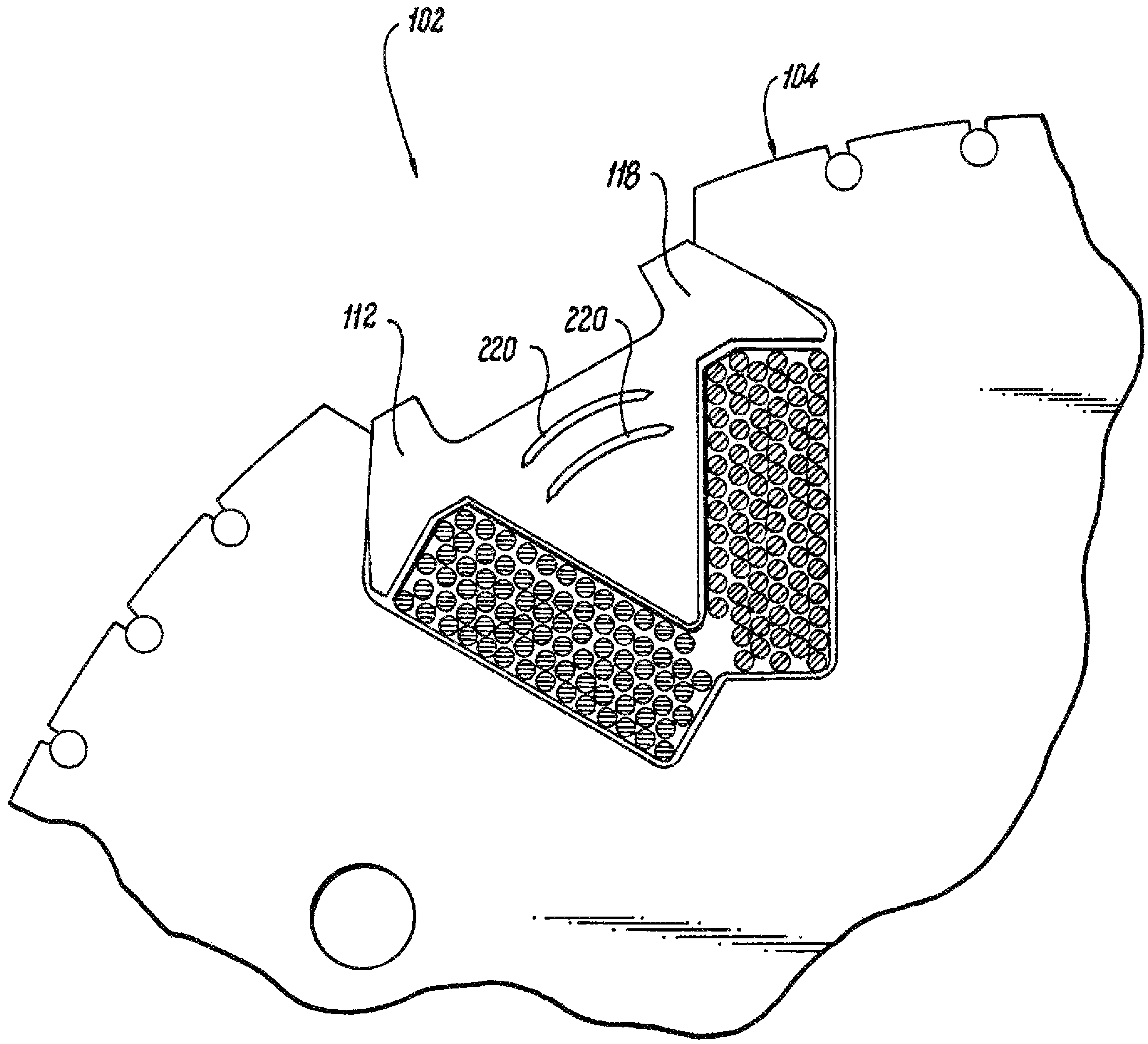
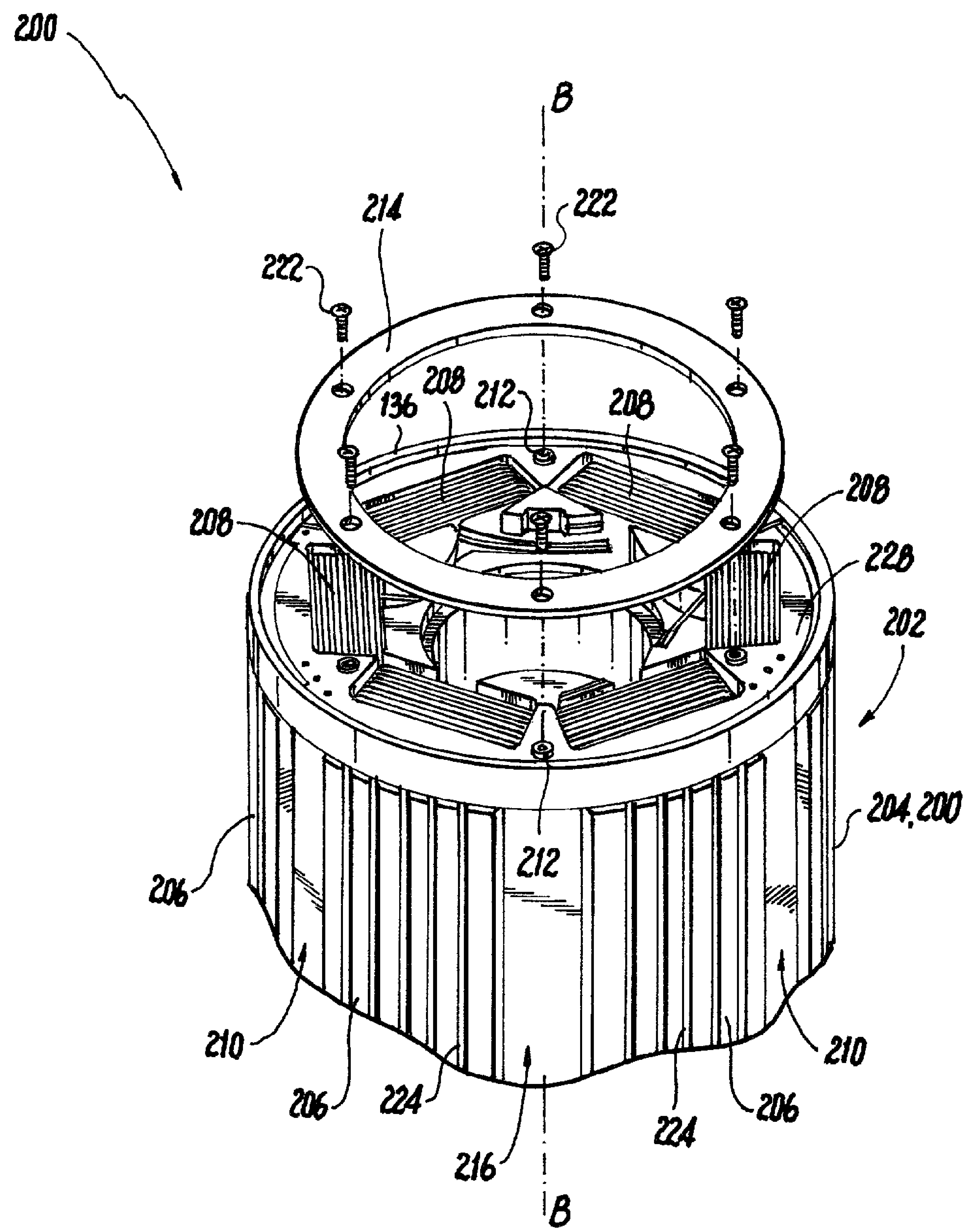


Fig. 3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B
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206
210

Fig. 4

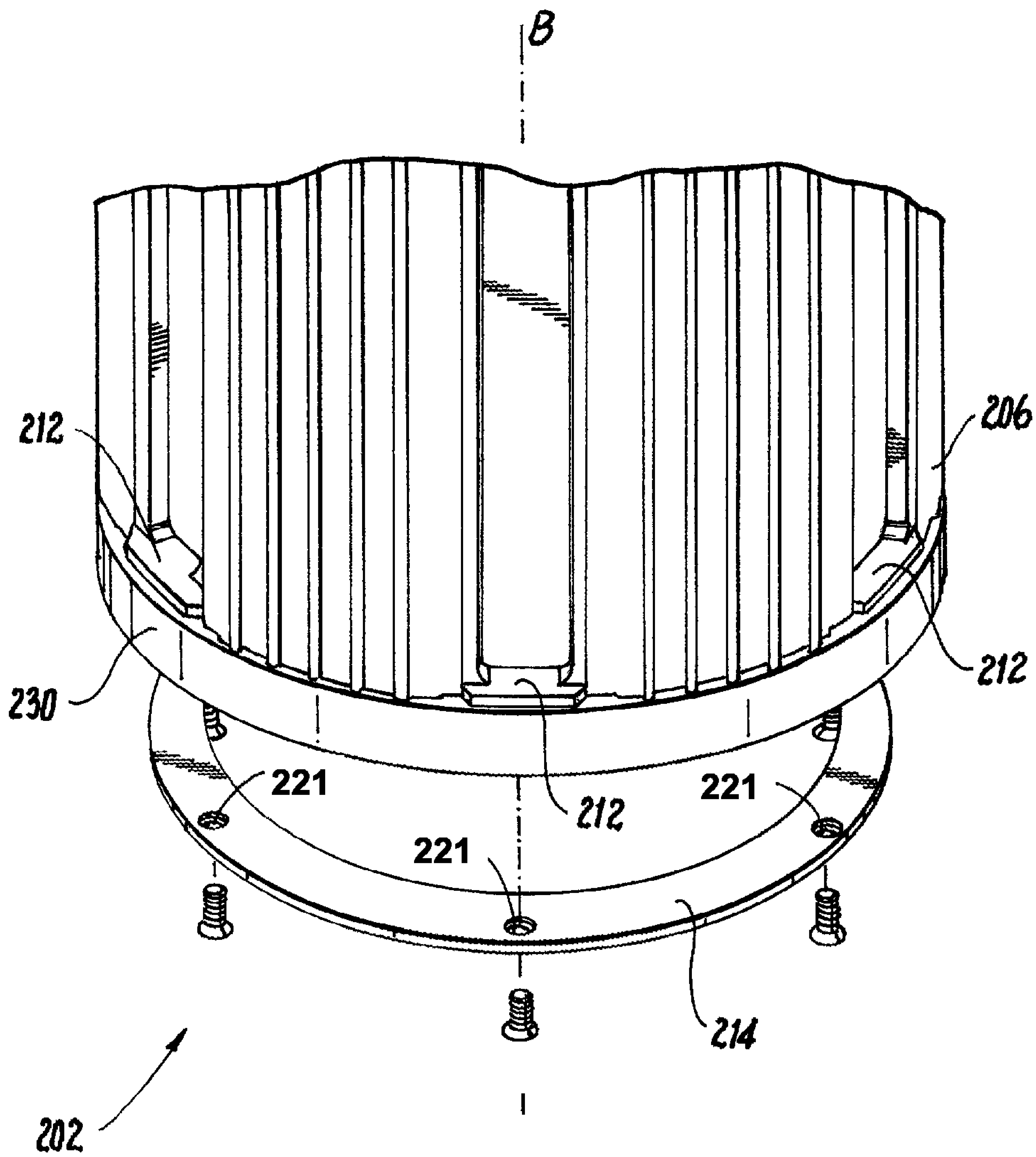

Fig. 5

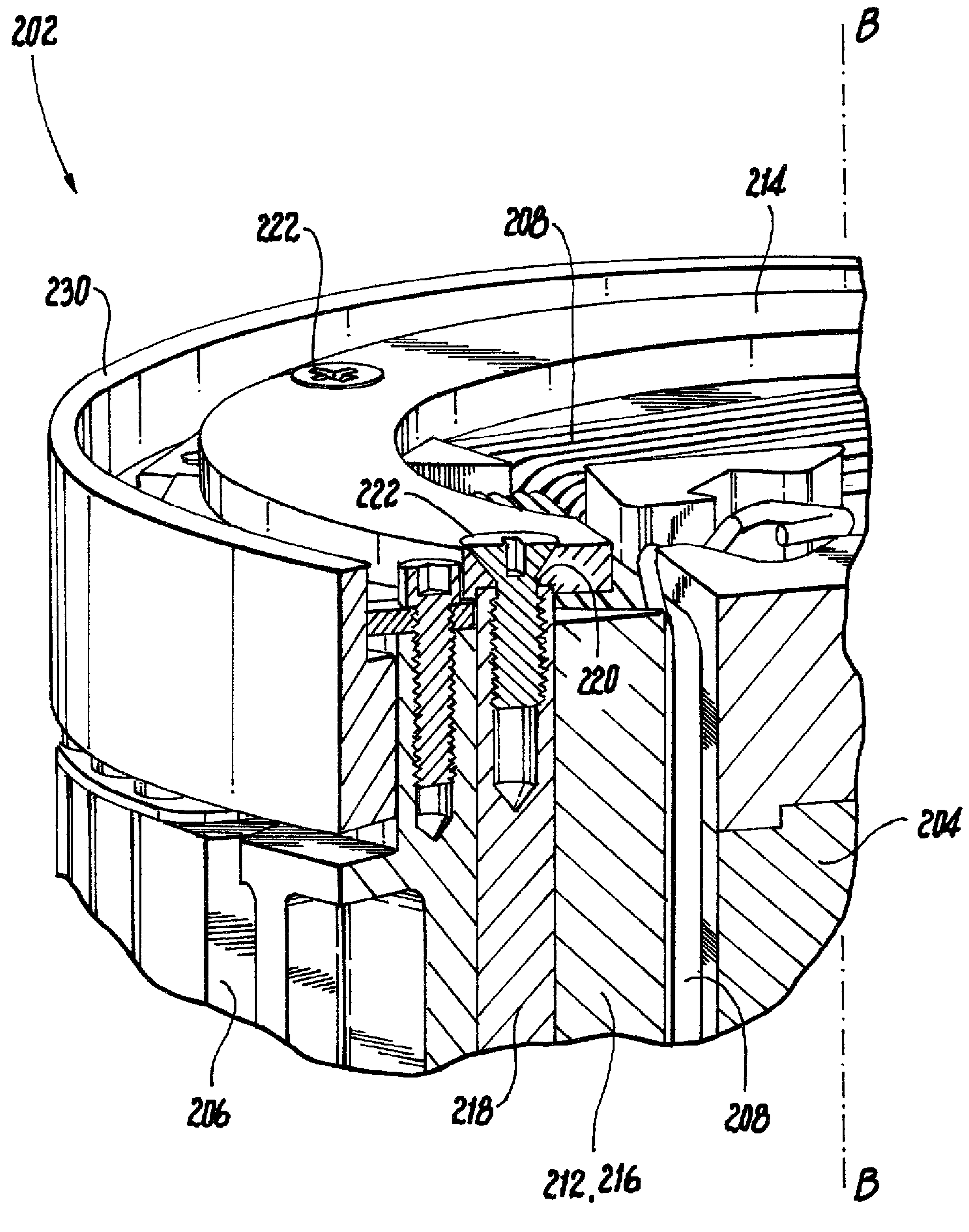

Fig. 6

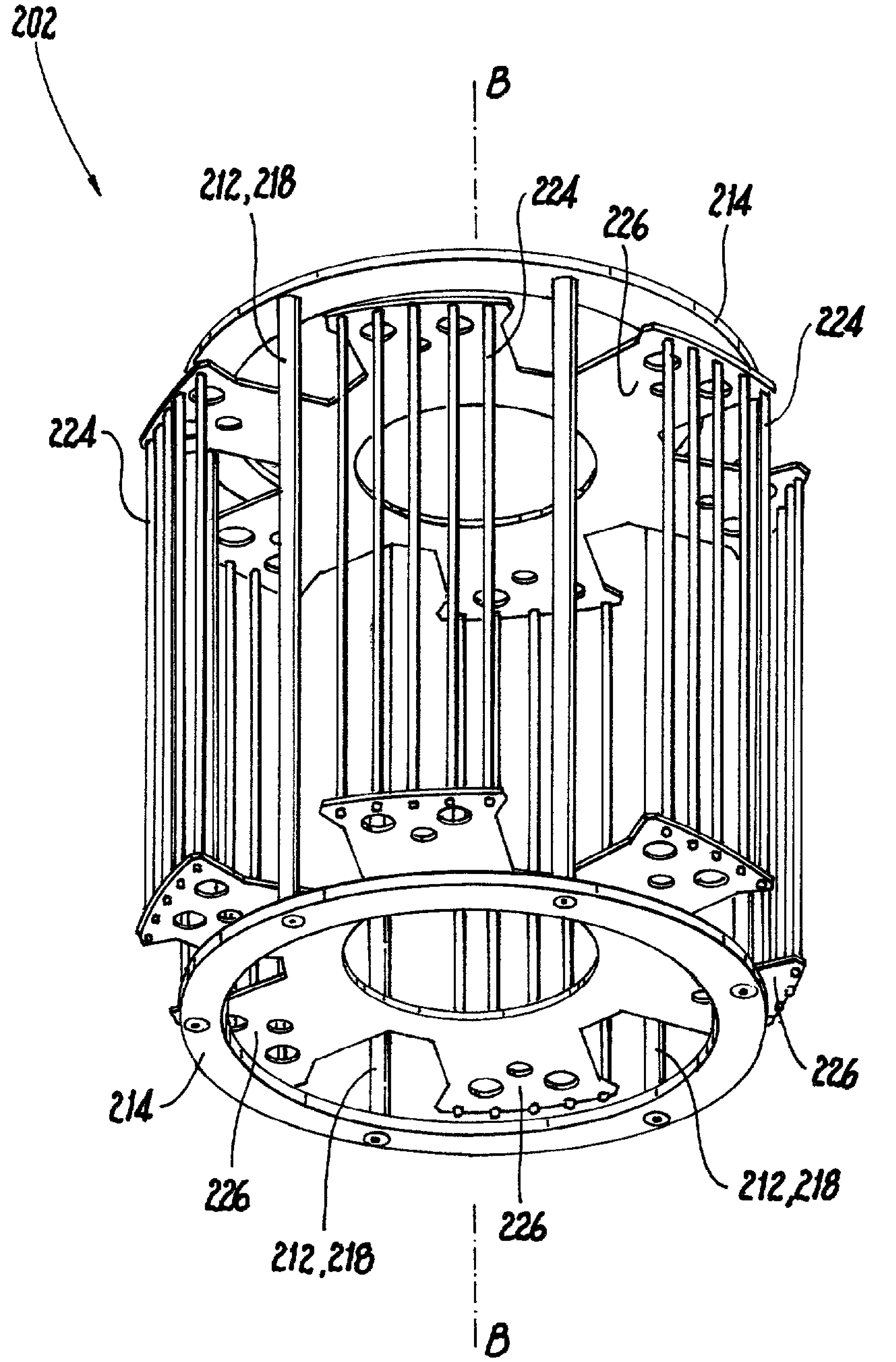
202
B
212,218
224
226
214
224
224
214
226
226
226
212,218
212,218
B

Fig. 7

WEDGES WITH Q-AXIS DAMPER CIRCUITS

CROSS-REFERENCE TO RELATED APPLICATIONS

This application is a continuation-in-part of U.S. patent application Ser. No. 15/470,525 filed Mar. 27, 2017 the contents of which are incorporated herein by reference in their entirety.

BACKGROUND

1. Field

The present disclosure relates to electrical machines, and more particularly to quadrature axis (Q-axis) damping in electrical machines.

2. Description of Related Art

One of the problems that face synchronous machines is the ability to reject disturbances caused by speed transients or load fluctuations and imbalances. In response to the electrical and mechanical disturbances, conventional synchronous machines have damper bars embedded into the rotors. The typical practice is to embed the damper bars in the direct axis of salient pole generators. However, this leaves the Q-axis undamped because the windings occupy the space between the poles of the rotor and it is typical to insert a wedge in the gap to hold the windings in place.

For high speed applications of electrical machines such as motors and generators, Q-axis damper windings are not practical because the wedge that holds the windings in place occupies the space where the Q-axis damper winding would occupy. The wedges are typically made of Inconel or titanium which is consistent in regards to poor conducting materials. In low speed applications, electrically conductive materials such as aluminum or copper can be used for the wedges. But these materials lack the strength needed in high speed, and/or high temperature applications. Additionally, the conductive wedge materials used in conventional low speed applications are typically electrically connected using braze joints, which are not strong enough for high speeds.

The conventional techniques have been considered satisfactory for their intended purpose. However, there is an ever present need for improved Q-axis damping. This disclosure provides a solution for this problem.

SUMMARY

A rotor for an electrical machine includes a rotor core having a plurality of circumferentially spaced apart rotor poles. A plurality of windings are seated in gaps between circumferentially adjacent pairs of the rotor poles. A respective wedge secures the windings in each gap configured to supply Q-axis damping. A pair of end plates are connected electrically to the wedges at opposing longitudinal ends thereof thereby completing a Q-axis winding circuit for each wedge.

The wedge can include a first member made of a first material and at least one second member made of a second material, the second material having a higher electrical conductivity than the first material, wherein the end plates electrically connect to the second member of each wedge. Each second member can extend into a respective counter sink formed in each respective end plate, and each end of each second member can be joined to the respective end plate with a fastener. The first material can have a higher strength than that of the second material.

At least one electrically conductive D-axis damper bar can extend longitudinally along a radially outer portion of each of the rotor poles, wherein the D-axis damper bars are electrically connected to each other, and wherein the wedges and the D-axis damper bars provide the rotor with full 360° damping circumferentially. The end plates can be Q-axis damper plates and an axially opposed pair of D-axis damper plates can be included, wherein each of the D-axis damper bars is connected between the D-axis damper plates. At each axial end of the rotor core, a respective one of the Q-axis damper end plates can be electrically isolated from a respective one of the D-axis damper plates, e.g., by being axially spaced apart therefrom by an insulator plate. A respective containment band can be wrapped around each axial end of the rotor core to radially contain the wedges in the gaps. The end plates can be electrically isolated from end windings of the windings.

These and other features of the systems and methods of the subject disclosure will become more readily apparent to those skilled in the art from the following detailed description of the preferred embodiments taken in conjunction with the drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

So that those skilled in the art to which the subject disclosure appertains will readily understand how to make and use the devices and methods of the subject disclosure without undue experimentation, preferred embodiments thereof will be described in detail herein below with reference to certain figures, wherein:

FIG. **1** is a schematic perspective view of an exemplary embodiment of apportion of an electrical machine constructed in accordance with the present disclosure, showing the D-axis and the Q-axis on a rotor;

FIG. **2** is a schematic end elevation view of a portion of the rotor of FIG. **1**, showing the damper bar in the wedge;

FIG. **3** is a schematic end elevation view of a portion of the rotor of FIG. **1**, showing another exemplary embodiment of a damper bar in the wedge;

FIG. **4** is an exploded perspective end view of a portion another embodiment of an electrical machine, showing the Q-axis damper plate at one end of the rotor core exploded from the rotor core;

FIG. **5** is an exploded perspective end view of the electrical machine of FIG. **4**, showing the counter sinks in the Q-axis damper plate;

FIG. **6** is a cross-sectional perspective view of a portion of the electrical machine of FIG. **4**, showing one of the fasteners joining the Q-axis damper plate to one of the wedges; and

FIG. **7** is a perspective view of a portion of the electrical machine of FIG. **4**, showing the D-axis damper plates and bars together with the Q-axis damper plates and wedge members with other components removed for clarity.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

Reference will now be made to the drawings wherein like reference numerals identify similar structural features or aspects of the subject disclosure. For purposes of explanation and illustration, and not limitation, a partial view of an exemplary embodiment of an electrical machine in accordance with the disclosure is shown in FIG. **1** and is designated generally by reference character **100**. Other embodiments of electrical machines in accordance with the disclosure, or aspects thereof, are provided in FIGS. **2-7**, as will be described. The systems and methods described herein can be used to provide quadrature axis (Q-axis) damping in high speed rotors of electrical machines where traditional rotors either lack Q-axis damping, or have some Q-axis damping structure that is too mechanically weak to support high speeds, e.g., 20,000 to 50,000 RPM.

A rotor **102** for the electrical machine **100** includes a rotor core **104** having a plurality of circumferentially spaced apart rotor poles **106**. Windings **108** are seated in gaps **110** between circumferentially adjacent pairs of the rotor poles **106**. A respective wedge **112** secures the windings **108** in each gap **110**. The rotor **102** rotates about axis A under forces created by stator **114** in a motor, or in a generator, the rotor **102** is driven by a prime mover. D-axis damper bars **116**, only some of which are labeled in FIG. **1** for sake of clarity, are provided in each of the poles **106** to provide damping for the D-axis in each pole **106**, where one of the D-axes is identified in FIG. **1**, which is the axis for the main flux for driving rotor **106** about axis A. Additional damper bars, e.g., as second member **120** described below, are provided in the materials of the wedges **112** to provide damping in the quadrature axis (Q-axis) through each gap **110**, where one of the Q-axes is shown in FIG. **1**.

With reference now to FIG. **2**, each wedge **112** includes a first member **118** made of a first material, such as titanium or Inconel, and a second member **120** made of a second material, such as copper, beryllium copper, or aluminum, with a higher electrical conductivity than that of the first material forming a damper bar for Q-axis damping. A pair of end plates **122**, one of which is shown in FIG. **1**, is electrically connected to the second member **120** of each of the wedges **110** to complete a Q-axis winding circuit for each wedge **110**.

The first member **118** has a higher mechanical strength than that of the second member **120**, providing strength for high speed rotation and/or high temperature operation, and the high electrical conductivity of the second material provides the electrical circuit for the Q-axis damper windings. It is also contemplated that the first material can have a higher melting or glass transition temperature than that of the second material. With electrically conductive damper bars **116** extending along an outer portion of each of the rotor poles **106**, wherein each damper bar **116** is electrically connected together for D-axis damping, and with the second member **120** of the wedges **112**, the collective damper bars **116/120** provide the rotor **102** with full 360° damping, where 360° is in reference to the direction wrapping circumferentially around rotation axis A of FIG. **1**.

The second member **120** in each wedge **112** forms a wedge damper bar extending axially through the respective wedge **112** from end to end. As shown in another embodiment shown in FIG. **3**, the second member **120** in each wedge **112** can form a plurality of damper bars **220** each forming an arc-shaped cross-section extending axially through the respective wedge **112**. The axial cross-sections of damper bars **220** have with a perimeter shaped for optimizing skin effect by the geometrical layout of the damper bar and the material selection. The at least one second member **120** is intimately radially surrounded by the first member **118**. Those skilled in the art will readily appreciate that this cross-sectional shape can be optimized for any given application. This adds a large amount of Q-axis transient inductance, which improves the transient performance of synchronous machines in accordance with this disclosure over conventional configurations. The shape can also be optimized to take advantage of the span/cross-sectional area available in the wedges **112**.

With reference again to FIG. **1**, each wedge **112** can have two axially opposed end portions **124** of a third material more electrically conductive than the first member **118** for electrical connection between the second member **120** and the end plates **122**. For example, each wedge including the first and second members **118** and **120** can be additively manufactured, and layers of copper or other suitable conductor can be additively manufactured to form the axial end portions **124** of each wedge **112**. The third material can be the same material as the second material or a different material from the second material. The wedges **112** can each be formed with n clearance space between the first and second members **118** and **120** thereof, e.g., by additive manufacturing. Then end plates **122** can be bolted to each end of rotor **102** as indicated by the bolt **126** and bolt holes **128** an **130** in FIG. **1**, and the end portions **124** will electrically connect the second members **120** in each wedge **122** with the end plates **122** to form Q-axis damping winding circuits. The plates **122** can welded rather than bolted to make the electrical connection in applications that require less structural capability. It is also contemplated that the plates **122** can be a ring that is pressed onto the outer diameter of the wedges **122** making contact via the interference fit to provide the electrical connection with the second member **120** in each wedge **122**.

Conventional high speed systems are utilized for high voltage DC and variable speed constant frequency systems. These systems require rectification, and the additional damper circuits as disclosed herein reduce the commutating resistance, thus making for more efficient systems than is possible with the conventional configurations.

With reference now to FIG. **4**, A rotor **202** for an electrical machine **200** (which can include a stator that is not pictured, but see stator **114** in FIG. **1**). The rotor **202** includes a rotor core **204** having a plurality of circumferentially spaced apart rotor poles **206**. A plurality of windings **208** are seated in gaps **210** between circumferentially adjacent pairs of the rotor poles **206**. A respective wedge **212** secures the windings in each gap **210** configured to supply Q-axis damping. A pair of end plates **214** (only one of which is shown in FIG. **4**, but see FIG. **7**) are connected electrically to the wedges **212** at opposing longitudinal ends thereof (relative to axis B) thereby completing a Q-axis winding circuit for each wedge **212**.

Each wedge **212** can include a first member **216** made of a first material and at least one second member **218** made of a second material as labeled in FIG. **6**. The first and second materials can be as described above with respect to FIGS. **1-3**. As shown in FIG. **7**, the end plates **214** electrically connect to the second member **218** of each wedge **212**. Each second member **218** can extend into a respective counter sink **221** (labeled in FIG. **5**) formed in each respective end plate **214**, and each end of each second member **218** can be joined to the respective end plate **214** with a fastener **222** as shown in FIG. **6**.

With reference now to FIG. **7**, at least one electrically conductive D-axis damper bar **224** can extend longitudinally along a radially outer portion of each of the rotor poles **206** (labeled in FIG. **1**). The D-axis damper bars **224** are electrically connected to each other so the wedges **212** and the D-axis damper bars **224** provide the rotor **202** with full 360° damping circumferentially. The end plates **214** are Q-axis damper plates and an axially opposed pair of D-axis damper plates **226** are included. Each of the D-axis damper bars **224** is connected electrically between the D-axis damper plates **226**. At each axial end of the rotor core, a respective one of the Q-axis damper end plates **214** is electrically isolated from a respective one of the D-axis damper plates **226**, e.g., by being axially spaced apart therefrom by an insulator plate **228** labeled in FIG. **4** about which the end windings of the windings **208** wind. FIG. **7** shows that the two respective damping cages are formed around rotor **202**, one including the D-axis damper bars **224** and end plates **226** for D-axis damping, and one including the second members **218** of the wedges **212** and end plates **214** for Q-axis damping, wherein the two cages are electrically isolated from one another. A respective containment band **230** (one shown in FIG. **4** and the other shown in FIG. **5**) is be wrapped around each axial end of the rotor core **202** to radially contain the wedges **212** in the gaps **210**. The end plates **214** and **226** can each be electrically isolated from end windings of the windings **208** by spacing and/or insulation.

The methods and systems of the present disclosure, as described above and shown in the drawings, provide for Q-axis damping with superior properties including full 360° damping coverage with mechanical strength for high speed and/or high temperature electrical machines, providing better performance for high voltage DC and variable speed constant frequency systems than traditional configurations. While the apparatus and methods of the subject disclosure have been shown and described with reference to preferred embodiments, those skilled in the art will readily appreciate that changes and/or modifications may be made thereto without departing from the scope of the subject disclosure.

What is claimed is:

1. A rotor for an electrical machine comprising:

a rotor core having a plurality of circumferentially spaced apart rotor poles;

a plurality of windings seated in gaps between circumferentially adjacent pairs of the rotor poles;

a respective wedge securing the windings in each gap configured to supply Q-axis damping; and

a pair of end plates connected electrically to the wedges at opposing longitudinal ends thereof thereby completing a Q-axis winding circuit for each wedge.

2. The rotor as recited in claim **1**, wherein the wedge includes a first member made of a first material and at least one second member made of a second material, the second material having a higher electrical conductivity than the first material, wherein the end plates electrically connect to the second member of each wedge.

3. The rotor as recited in claim **2**, wherein each second member extends into a respective counter sink formed in each respective end plate, and wherein each end of each second member is joined to the respective end plate with a fastener, and/or wherein the first material has a higher strength than that of the second material.

4. The rotor as recited in claim **1**, further comprising at least one electrically conductive D-axis damper bar extending longitudinally along a radially outer portion of each of the rotor poles, wherein the D-axis damper bars are electrically connected to each other, wherein the wedges and the D-axis damper bars provide the rotor with full 360° damping circumferentially.

5. The rotor as recited in claim **4**, wherein the end plates are Q-axis damper plates and further comprising an axially opposed pair of D-axis damper plates, wherein each of the D-axis damper bars is connected between the D-axis damper plates.

6. The rotor as recited in claim **5**, wherein at each axial end of the rotor core, a respective one of the Q-axis damper end plates is electrically isolated from a respective one of the D-axis damper plates.

7. The rotor as recited in claim **6**, wherein at each axial end of the rotor core, a respective one of the Q-axis damper end plates is axially space apart from a respective one of the D-axis damper plates.

8. The rotor as recited in claim **6**, wherein at each axial end of the rotor core, a respective one of the Q-axis damper end plates is axially space apart from a respective one of the D-axis damper plates by a respective insulator plate.

9. The rotor as recited in claim **1**, further comprising a respective containment band wrapped around each axial end of the rotor core to radially contain the wedges in the gaps.

10. The rotor as recited in claim **1**, wherein the end plates are electrically isolated from end windings of the windings.

* * * * *